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A STUDY OF THE EFFECTS OF BRAKING ON DRAG FORCE AND SINKAGE

J. L. Smith, et al

Army Engineer Waterways Experiment Station

Prepared for:

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August 1975

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A STUDY OF THE EFFECTS OF BRAKING ON DRAG FORCE & SINKAGE

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US Army Engineer Waterways Experiment Station
Vicksburg, MS 39181

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Final Report for Period June 1966 to December 1966

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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To determine the effect of braking on drag force and sinkage and to ascertain the feasibility of scale-modeling the apparatus, braked wheel tests were conducted at low forward speed in highly saturated, very plastic buckshot clay and in air-dry Yuma desert sand with two tires that were essentially 1:2 scale models of one another, a 4.00-7, 2-PR and a 9.00-14, 2-PR, each at 25 percent tire deflection. Test in both soils produced braked-wheel slip values from 0 to 100 percent. Dimensionless numerics Cbd/W and $G_b(bd)^{3/2}/W$

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used in previous studies to describe powered-wheel performance in clay and in sand, respectively, had to be revised to describe braked-wheel performance adequately.

For the range of test conditions in clay, drag/load (D/W) is closely related to $C^2bd/W(S)^{1/2}$ (S= slip) and sinkage/tire diameter^2 (z/d^2) to $Cbd/W(S)^{1/10}$. The dimensional terms $C^2bd/W(S)^{1/2}$ and z/d^2 are thought to be part of dimensionless terms $C^2bd/WpV_c^2(S)^{1/2}$ and zV_c^2/d^2g, respectively. Proofs of these hypotheses await future test in which variables V_c and p, and variable V_c, respectively, take a range of values. For the sand tests, D/W is closely related to braked-wheel slip in the 20 to 100 percent range, but the data appear to separate by tire size (only) between 0 and 20 percent slip. In sand, braked-wheel z/d can be predicted from dimensionless numeric $[G_b(bd)^{3/2}/W] \cdot (1 - S^{1/2})$.

PREFACE

This investigation was conducted under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, formerly Chief and Assisstant Chief, respectively, Soils Division (now Soils and Pavements Laboratory, SPL), and Messrs. W. G. Shockley and S. J. Knight, Chief and former Assisstant Chief, respectively, Mobility and Enviromental Division (now Mobility and Enviromental Systems Laboratory, MESL). The program was supervised directly by Dr. D. R. Freitag, former Chief, Mobility Research Branch (now Mobility Research and Methodology Branch, MRMB, of the Mobility Systems Division, MSD), and Mr. J. L. Smith, Chief, Data Handling Branch, MSD. The laboratory tests were conducted by personnel of the Mobility Investigations Branch, MSD. Resulting data were analyzed and this report was prepared by Messrs. Smith and G. W. Turnage, MRMB.

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TABLES

ABBREVIATIONS AND SYMBOLS

C	Cone Index
D	Drag force
G_b	Cone index gradient
L	Characteristic linear dimension
N_c	Clay numeric*
N_s	Sand numeric*
PR	Ply rating
S	Braked-wheel slip
V	Velocity in fluid mechanics relations
V_c	Carriage forward speed
V_w	Wheel peripheral speed
W	Wheel load
b	Tire section width
d	Tire diameter
g	Acceleration of gravity
p	Pressure
z	Tire sinkage
ρ	Mass density

* Subscripts c1, c2, c3, c4, s1, and s2 indicate various forms of the numerics.

SECTION I

INTRODUCTION

1. BACKGROUND

Under present day concepts of warfare, it is essential that the military organization be able to airlift men and equipment quickly into any area of operations and to furnish support while they are there. Very often, airfields do not exist, are too few, or are not close enough to the battle area to be used for support operations. Normal construction of an airfield requires a great deal of time and money, as well as a considerable outlay of equipment, none of which may be available in a given situation. As an alternative, it has been suggested that cargo aircraft land on unsurfaced runways that have received only a minimum of preparation. This, of course, requires landing gear designed to withstand the drag force and wheel sinkage associated with soft soils.

Some of the parameters that affect drag force and sinkage are load, soil strength, tire size, tire deflection, velocity, and slip (braking). The effects of these parameters on drag force and sinkage have been determined, except for velocity and braking, from tests with powered and freely rolling model and prototype pneumatic tires in soft soils conducted over the past several years by the Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES) (reference 1). Through the use of dimensional analysis techniques, it has been shown that the parameters measured in model tests can be used to predict values for the prototype tires tested to date (reference 2). This suggests that the problem of determining the effect of braking on drag force and sinkage also would lend itself to model analysis. Therefore, a program of model tests using braked wheels was conducted as a joint effort between the MESL and the Soils and Pavements Laboratory at WES.

2. PURPOSE

The specific purposes of this study were to (a) determine the effect of braked-wheel slip on drag force and sinkage, and (b) ascertain

whether a scale model can be used to predict behavior of prototypes under conditions of high braked-wheel slip in a given soil.

3. SCOPE

Braked-wheel performance tests were conducted, some under conditions of constant braking (constant slip), and the remainder under conditions of programmed braking (slip progressing linearly from 0 to 100 percent). The analysis herein considers only first-pass wheel performance data. Tests were conducted on a fat clay and on a dry sand with the average initial strength of the soils (cone index) ranging from 20 to 60 in the 0- to 6-in. layer. Two tires were tested, a 4.00-7, 2-PR and a 9.00-14, 2-PR at one tire deflection, 25 percent.

SECTION II

TEST PROGRAM

1. TEST FACILITY

The test program was conducted in the mobility small-scale-testing facility (figure 1) of the WES. A detailed description of this facility and the test techiques used can be found in reference 1a.

2. SOILS AND THEIR PREPARATION

The soils used in this study were classified as fat clay (CH) and fine sand (SP-SM), respectively, according to the Unified Soil Classification System. The clay was a Mississippi River alluvium obtained from the Long Lake area northwest of Vicksburg, Mississippi. The sand was obtained from dunes near Yuma, Arizona. Gradation and classification data for the two soils are shown in figure 2.

The clay was prepared to the desired consistency in a pug mill, which mixed soil and water at predetermined rates of flow. The prepared soil flowed from the pug mill into a test bin that was propelled slowly back and forth to allow uniform distribution of the soil. Next, the soil was compacted with a pneumatic-tired roller to a density corresponding to about 95 percent saturation, and then cured for approximately 11 days.

All the sand was air dried. To achieve different soil strengths, the density was varied by placing the sand in bins in uniform layers and screeding and vibrating it from the surface as required to achieve the desired strength (reference 1a).

3. TEST TIRES

The two test tires were the 4.00-7, 2-PR and the 9.00-14,2-PR, which were selected for use in this study primarily because they are essentially 1:2 scale models of one another.

4. TEST PROCEDURES

Three tests were conducted in each soil for each combination of tire size, soil strength, and wheel load used. Two of these were braked-wheel, constant-slip tests (40 and 80 percent); the third was a braked-wheel,

programmed-increasing-slip test (0 to 100 percent). The speed of advance of the carriage (V_c) was held constant at 5 fps and the peripheral speed of the wheel (V_w) was adjusted to obtain different slip values. The term "braked-wheel slip" as used herein is defined as $1-(V_w/V_c)$. By computing slip in this manner, a fully braked wheel is shown to be operating at 100 percent positive slip when $V_w = 0$. It should be noted that braked-wheel slip, as defined, is a dimensionless number.

Moisture and density of the soil were determined before and after traffic, and cone index was measured before, during, and after traffic. Measurements of drag force, sinkage, tire deflection, wheel load, and slip were recorded continuously during each pass of the wheel.

SECTION III

ANALYSIS OF TEST RESULTS

1. PRESENTATION OF DATA

The tire, soil, and performance data used in the analysis are listed in tables I and II. To determine whether tests with braked wheels would lend themselves to model theory, results obtained in an earlier dimensional analysis (reference 2) of the tire-soil system with powered wheels were used. Among other things, this dimensional analysis showed that both the ratio of drag force of a free-rolling wheel to wheel load (D/W), hereafter called the drag ratio, and the ratio of sinkage to tire diameter (z/d), hereafter called the sinkage ratio, are related to a dimensionless numeric in which variables of soil strength, load, and tire geometry are combined.

The basic numeric for clay is

$$N_{c1} = \frac{Cbd}{W} \tag{1}$$

where

C = cone index, psi

b = undeflected tire section width, in.

d = undeflected tire diameter, in.

W = wheel load, lb

The basic numeric for sand is

$$N_{s1} = \frac{G_b (bd)^{3/2}}{W} \tag{2}$$

where

G_b = average cone index gradient over a depth equal to the sectional width of the tire

Tire sizes, wheel loads, and soil strengths for this test program were chosen mainly to meet the scaling requirements of dimensional analysis techniques. In this analysis, braked-wheel drag force and slip are plotted as positive numbers.

2. TESTS IN CLAY

The first step was to determine whether N_{c1} is applicable to the analysis of the braked-wheel performance of pneumatic tires operating in clay. If it is adequate to account for the effects of load, soil consistency, and tire size (circular-cross-section tires only), the relation between N_{c1} and each dependent performance parameter should be described by a single line.

a. Drag Ratio

The drag ratio (D/W) is plotted versus N_{c1} in figure 3 for tests with the 4.00-7 tire (open symbols) and the 9.00-14 tire (closed symbols) operating at approximately 40 percent braked-wheel slip. The data cannot be described by a single line, indicating that one or more of the variables in the basic numeric are not in the proper ratio. Therefore, N_{c1} does not adequately correlate with the drag ratio under conditions of braking. However, the data do suggest what the proper form of the numeric should be. For example, figure 3 shows that the data points group by cone index. The loads within each group are not equal, but are approximately proportional to the tire size. The fact that data from both sizes of tires plot together as long as the cone index is nearly constant indicates that the difference in the applied load is not the source of variation. Since all data were obtained at one braked-wheel slip, slip is not a factor in the analysis at this point.

The above results suggest that cone index is the variable that is not in proper scale. When the cone index value in equation 1 is squared, yielding

$$N_{c2} = \frac{C^2bd}{W} \tag{3}$$

and N_{c2} is plotted versus the drag ratio, a single relation results (figure 4). This implies that a change in cone index has a greater absolute effect on drag force in the braked-wheel condition than it does on pull in the powered-wheel condition (reference 2). However, N_{c2} is not dimensionless, so additional variables are required to restore the dimensionless condition.

Other work in progress at the WES has shown that cone index is rate dependent. This rate dependency may explain the additional effect of cone index, and the term required to account for it could very well be the additional variable needed for dimensional balance. One of the classic dimensionless parameters of fluid mechanics is $\rho V^2/p$, where ρ is mass density, V is velocity, and p is pressure. If cone index is substituted for pressure, and if it is assumed that velocity is the forward speed of the carriage (V_c) and that ρ is the mass density of the soil, and if the inverse of this dimensionless parameter is multiplied by N_{c1}, the result is the dimensionless term $C^2bd/W\rho V_c^2$. The degree of association between $C^2bd/W\rho V_c^2$ and drag ratio is essentially the same as between N_{c2} and drag ratio for the data of this test program because forward velocity V_c and soil mass density were nearly constant for all tests. A check on the effectiveness of $C^2bd/W\rho V_c^2$ in describing drag ratio must await future tests in which values of V_c and ρ are varied.

Equation 3 collapsed the drag ratio data for one value of braked-wheel slip; a family of curves (figure 5) defines this relation for four levels of slip. The data at N_{c2} = 200 are cross plotted in figure 6.

Since the slope of the line in figure 6 is 1:2 on a logarithmic plot, the separation between the curves in figure 5 is proportional to the square root of braked-wheel slip, i.e., $S^{1/2}$, another dimensionless number. Drag ratio data are plotted in figure 7 versus

$$N_{c3} = \frac{C^2bd}{W(S)^{1/2}} \qquad (4)$$

The data collapse along a single curve, indicating that N_{c3} adequately describes the effects of soil strength, load, tire geometry, and braked-wheel slip on changes in the drag ratio. However, to determine with certainty whether this or some other arangement of variables is correct, additional tests should be run in which each of the variables is studied over a range of values.

a. Drag Ratio

Drag ratio data from tests conducted with both the 4.00-7 (open symbols) and the 9.00-14 (closed symbols) tires at several values of braked-wheel slip are plotted versus N_{s1} in figure 11. From the relations shown, drag ratio appears to be independent of N_{s1}, especially at 20 and 40 percent braked-wheel slip (figures 11b and 11c). The independence is not as apparent in the 12 and 80 percent data, but this is thought to be the result of data scatter associated with the extreme slip conditions. The reason for the apparent separation by tire sizes in figures 11a and 11b is not known. A stong dependence of drag force on braked-wheel slip can also be seen in figure 11.

To investigate these relations, drag ratio was plotted versus braked-wheel slip (figure 12) for all the tests in sand used in this study. Figure 12 shows that drag ratio is uniquely related to slip for all conditions tested, except possibly between 0 and 20 percent. It seems possible that at slips between 20 and 100 percent, the shoving action of the braked tire creates a mass of soil ahead of the wheel whose strength tends to be constant. This would effectively negate the effects of strength differences in the original soil. A considerable amount of scatter occurs at high braked-wheel slips in the data shown in figure 12, but there is a definite intermingling of data for all test conditions from 20 to 100 percent slip. The data in this range do not separate on the basis of tire size. The reason for the separation in the 0 to 20 percent slip range is not understood, and further studies are needed before an attempt is made to explain it. The data in figure 12 make it clear that, for the greater part of the braked-wheel slip range, the drag force depends primarily on load and slip in sand. This suggests that the drag force relation is almost entirely dependent on frictional resistance developed at the tire-soil interface.

b. Sinkage Ratio

In figure 8 the sinkage ratio (z/d) is plotted versus N_{c1} for both tires operating braked-wheel at approximately 40 percent slip. Data are from the same tests as those used in figure 3. The data in figure 8 tend to separate on the basis of tire size, particularly for large values of the sinkage ratio. As with the drag ratio, equation (1) is not adequate for developing a correlation with sinkage ratio under braking conditions. The tendency of the sinkage ratio data to separate by tire size indicates that a necessary linear dimension is missing. This is substantiated by the observation that the data collapse, particularly at high values of the sinkage ratio, much better if the sinkage ratio values for the 9.00-14 tire are divided by 2.

Since the linear scale of the model-prototype system is also 2, the data in figure 8 can be collapsed by dividing the sinkage ratio values by tire diameter, yielding a revised ratio, z/d^2. The data have been replotted using this revised ratio in figure 9. A much better correlation is attained between z/d^2 and N_{c1} in figure 9 than was present between z/d and N_{c1} in figure 8, particularly for large values of the ordinate terms.

It should be noted that a relation similar to the one shown in figure 9 would result if values of the sinkage ratio were divided by the tire width, or by some combination of tire width and diameter that would result in a unit of length. The proper combination to make such a relation valid for any tire size could not be ascertained from this limited test program. To determine this would require additional tests in which one of the parameters is varied while the others are held constant.

The introduction of an additional term in the sinkage ratio destroys the dimensionless character of the relation; therefore, other variables must be included to restore proper dimensional balance. Other work at the WES, discussed on page 7, has shown the properties of clay to be rate dependent: this rate dependency could very well be the source of the additional parameters necessary for dimensional balance. For example, dimensional balance would result if the Froude number V^2/Lg were used, where V is velocity, L is a characteristic linear dimension of the system,

and g is the acceleration of gravity. If the diameter d is substituted for L and forward carriage speed V_c for V in the Froude number, and if the resulting dimensionless parameter is multiplied by z/d, the result is zV_c^2/d^2g. Carriage speed and acceleration of gravity were constant in this test program, so proof of this hypothesis requires that tests be conducted in which speed is a variable.

The revised sinkage ratio (z/d^2) collapsed the sinkage data for one value of braked-wheel slip. A procedure following that shown in figures 5 and 6 for drag was applied to sinkage, and it was established that, at any single value of N_{c1}, the revised sinkage ratio is approximately proportional to the tenth root of braked-wheel slip, resulting in

$$N_{c4} = \frac{Cbd}{W(S)^{1/10}} \tag{5}$$

The relations of the revised sinkage ratio versus N_{c4} are shown in figure 10. Although there is some scatter, especially at very low values of the revised sinkage ratio, all the data now can be described by a single curve, indicating that the revised sinkage ratio and N_{c4} can reasonably well describe changes in sinkage.

The scatter of low values of the revised sinkage ratio occurred partly because the sinkages were so small that they were difficult to measure accurately. Scatter at all values of the ratio is thought to result primarily from variation in the original sinkage measurements caused by nonuniformities in soil strength and from the tire continually picking up and depositing clay as it progressed down the traffic lane. Because of the variation in the original sinkage measurements, the accuracy of the exponent 1/10 in equation (5) is somewhat questionable.

3. TESTS IN SAND

The analysis of the data from braked-wheel tests in sand followed the same pattern as the analysis of data from tests in clay. The preliminary goal was to determine if the drag and sinkage ratios respond in a unique and predictable manner to changes in the basic sand numeric (N_{s1}, equation 2).

b. Sinkage Ratio

The relation of sinkage ratio values to N_{s1} at four levels of braked-wheel slip is described by a family of curves of similar shape in figure 13. To collapse these data to a single curve, the function $1 - S^{1/2}$ was used, yielding

$$N_{c2} = \frac{G_b (bd)^{3/2}}{W\left(1-S^{1/2}\right)} \tag{6}$$

The degree of collapse achieved with equation (6) is shown in figure 14. The good fit verifies that N_{s2} describes tire sinkage performance quite well in the braked-wheel condition.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

Based on the analysis of data from the braked-wheel tests reported herein, the following conclusions are drawn:

a. The basic numerics N_{c1} and N_{s1} used to describe powered-wheel performance in clay and in sand, respectively, can be revised to predict braked-wheel tire sinkage if tire diameter is squared in the sinkage ratio (z/d^2) for clay, and if the appropriate functions of slip are included in the revised numerics (equation 5 for clay and equation 6 for sand).

b. For the range of conditions tested in clay, drag ratio (drag/load) is closely related to N_{c3}, a numeric different from N_{c1} in that N_{c3} includes a function of slip and C^2 (cone index squared) instead of C--see equation (4).

c. For the sand tests, drag ratio is closely related to braked-wheel slip in the 20 to 100 percent range. Between 0 and 20 percent slip, the data appear to separate by tire size, but not by any other variable included in this test program (figure 12).

d. Because the performance data of the two test tires (whose major dimensions differ by a ratio of approximately 1:2) can be collapsed using the revised dimensionless numerics (equations (4), (5), and (6) and figures 7, 10, and 14, respectively), there is a good possibility that results of scale-model tire tests can be used to predict prototype tire behavior under braked-wheel conditions both in clay and in sand.

2. RECOMMENDATIONS

To determine the final forms of the numerics that will accurately predict performance of tires operating under braking conditions, it is recommended that:

_a_. Further braked-wheel tests at a range of speeds be conducted in clay of different densities to determine the terms required to make the numeric for predicting drag/load dimensionless.

_b_. Data from these additional tests be analyzed to check the exponent of the slip term in the numeric for predicting sinkage/tire diameter (equation (5)).

_c_. Tests be conducted in sand to discover the significance of the separation of data by tire size in the relation between drag/load and braked-wheel slip below 20 percent.

TABLE I.--FIRST-PASS BRAKED-WHEEL TESTS IN BUCKSHOT CLAY

Test No.	Carriage Speed V_c fps	Cone Index C	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Clay Numeric N_{c1}*	Clay Numeric N_{c2}*	Clay Numeric N_{c3}*	Clay Numeric N_{c4}*
36	4.92	29	4.19	14.12	0.06	186	83	0.372	0.448	0.004	9.22	267.4	438.4	10.18
37	5.03	32	4.19	14.12	0.22	191	121	0.799	0.634	0.016	9.91	317.1	354.7	10.13
38	4.92	31	4.22	14.14	1.38	377	289	0.773	0.774	0.098	4.91	152.2	173.2	5.04
39	4.89	17	4.19	14.12	1.96	185	186	0.785	1.026	0.139	5.44	92.5	104.4	5.57
40	4.97	17	4.19	14.12	1.47	185	170	0.351	0.926	0.104	5.44	92.5	156.3	6.03
41	5.04	17	4.19	14.12	1.14	181	61	0.034	0.337	0.081	5.56	94.5	513.6	7.80
	5.07	17	4.19	14.12	1.24	177	112	0.128	0.633	0.088	5.68	96.6	269.8	6.98
	4.94	17	4.19	14.12	1.37	187	135	0.193	0.722	0.097	5.38	91.5	208.4	6.34
	4.95	17	4.19	14.12	1.34	195	158	0.280	0.810	0.095	5.16	87.7	165.8	5.86
	5.00	17	4.19	14.12	1.03	178	144	0.348	0.809	0.073	5.65	96.1	162.9	6.28
	5.02	17	4.19	14.12	1.20	182	157	0.371	0.863	0.085	5.53	94.0	154.4	6.10
	5.06	17	4.19	14.12	1.30	187	159	0.451	0.850	0.092	5.38	91.5	136.2	5.83
	5.06	17	4.19	14.12	1.34	184	171	0.521	0.929	0.095	5.46	92.8	128.5	5.83
	5.07	17	4.19	14.12	1.37	174	172	0.597	0.988	0.097	5.78	98.3	127.2	6.08
	5.08	17	4.19	14.12	1.57	186	184	0.672	0.989	0.111	5.41	92.0	112.2	5.63
	5.11	17	4.19	14.12	1.51	186	176	0.745	0.946	0.107	5.41	92.0	106.6	5.57
	5.10	17	4.19	14.12	1.49	181	174	0.783	0.961	0.106	5.55	94.4	106.7	5.69
	5.09	17	4.19	14.12	1.55	185	175	0.819	0.946	0.110	5.44	92.5	102.2	5.55
	5.09	17	4.19	14.12	1.56	183	176	0.889	0.962	0.110	5.49	93.3	98.9	5.56
42	4.70	29	4.19	14.12	0.24	197	29	0.058	0.147	0.017	8.71	252.6	1049	11.58
	4.73	29	4.19	14.12	0.27	200	76	0.153	0.380	0.019	8.53	248.8	636.3	10.35
	4.71	29	4.19	14.12	0.31	196	86	0.240	0.439	0.022	8.75	253.8	518.0	10.09
	4.68	29	4.19	14.12	0.31	191	94	0.324	0.492	0.022	8.98	260.4	457.6	10.06
	4.70	29	4.19	14.12	0.49	192	100	0.381	0.521	0.035	8.94	259.3	420.3	9.85

(Continued)

* Equations 1, 3, 4, and 5, respectively.

(Sheet 1 of 4)

TABLE I. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index C	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Clay Numeric N_{c1}*	Clay Numeric N_{c2}*	Clay Numeric N_{c3}*	Clay Numeric N_{c4}*
42	4.71	29	4.19	14.12	0.47	186	90	0.409	0.484	0.033	9.23	267.7	418.3	10.10
	4.89	29	4.19	14.12	0.52	190	113	0.503	0.595	0.037	9.03	261.9	369.2	9.67
	4.98	29	4.19	14.12	0.52	193	105	0.585	0.544	0.037	8.89	257.8	337.1	9.38
	4.98	29	4.19	14.12	0.31	203	105	0.660	0.517	0.022	8.45	245.1	301.7	8.81
	4.98	29	4.19	14.12	0.25	194	86	0.730	0.443	0.018	8.84	256.4	300.2	9.12
	5.03	29	4.19	14.12	0.22	194	103	0.791	0.531	0.016	8.84	256.4	288.4	9.05
	5.08	29	4.19	14.12	0.38	191	117	0.864	0.612	0.027	8.98	260.4	280.3	9.12
	5.10	29	4.19	14.12	0.31	198	110	0.933	0.556	0.022	8.67	251.4	260.2	8.73
43	4.99	33	4.22	14.14	1.06	373	106	0.052	0.284	0.075	5.28	174.2	764.0	7.10
	4.99	33	4.22	14.14	1.09	378	158	0.139	0.418	0.077	5.21	171.9	461.1	6.35
	4.98	33	4.22	14.14	1.09	378	193	0.218	0.510	0.077	5.21	171.9	368.2	6.07
	5.00	33	4.22	14.14	1.04	387	222	0.302	0.574	0.074	5.09	168.0	305.5	5.74
	5.01	33	4.22	14.14	1.08	368	219	0.356	0.595	0.076	5.35	176.6	295.9	5.93
	5.01	33	4.22	14.14	1.27	373	236	0.383	0.633	0.090	5.28	174.2	281.5	5.81
	5.01	33	4.22	14.14	1.51	378	253	0.459	0.669	0.107	5.21	171.9	253.7	5.63
	5.01	33	4.22	14.14	1.46	375	273	0.535	0.728	0.103	5.25	173.3	236.9	5.59
	5.01	33	4.22	14.14	1.51	378	302	0.604	0.799	0.107	5.21	171.9	221.2	5.48
	5.04	33	4.22	14.14	1.40	379	312	0.674	0.823	0.099	5.19	171.3	208.8	5.40
	5.00	33	4.22	14.14	1.46	362	340	0.745	0.939	0.103	5.44	179.5	208.0	5.60
	5.00	33	4.22	14.14	1.60	385	355	0.784	0.922	0.113	5.11	168.6	190.6	5.24
	5.04	33	4.22	14.14	1.42	363	336	0.818	0.926	0.100	5.42	178.9	197.9	5.53
	5.06	33	4.22	14.14	1.72	378	341	0.898	0.902	0.122	5.21	171.9	181.4	5.27
44	4.93	39	4.22	14.14	1.20	386	238	0.335	0.616	0.085	6.03	235.2	406.2	6.73
45-49**	--	--	--	--	--	--	--	--	--	--	--	--	--	--

(Continued)

** Tests 45-49 were conducted to determine relations not sought in this program.

(Sheet 2 of 4)

TABLE I. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index C	Tire Width b in.	Tire Diam d in.	Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Clay Numeric N_{c1}*	Clay Numeric N_{c2}*	Clay Numeric N_{c3}	Clay Numeric N_{c4}*
50	5.08	20	8.26	28.30	1.93	766	240	0.074	0.313	0.068	6.10	122.0	448.7	7.91
	5.06	20	8.26	28.30	2.20	750	368	0.154	0.491	0.078	6.23	124.6	317.7	7.52
	5.10	20	8.26	28.30	2.66	764	458	0.252	0.599	0.094	6.12	122.4	243.8	7.03
	5.06	20	8.26	28.30	2.76	750	548	0.327	0.731	0.098	6.23	124.6	218.0	6.97
	5.08	20	8.26	28.30	2.86	752	586	0.350	0.779	0.101	6.22	124.4	210.2	6.91
	5.12	20	8.26	28.30	3.00	758	650	0.411	0.858	0.106	6.17	123.4	192.4	6.74
	5.13	20	8.26	28.30	3.07	752	689	0.490	0.916	0.108	6.22	124.4	177.6	6.68
	5.14	20	8.26	28.30	3.31	764	705	0.564	0.923	0.117	6.12	122.4	163.0	6.48
	5.12	20	8.26	28.30	3.07	750	733	0.638	0.977	0.108	6.23	124.6	156.1	6.52
	5.16	20	8.26	28.30	3.27	760	699	0.706	0.920	0.116	6.15	123.0	146.4	6.37
	5.15	20	8.26	28.30	3.22	762	737	0.772	0.967	0.114	6.14	122.8	139.7	6.30
	5.16	20	8.26	28.30	3.24	750	740	0.785	0.987	0.114	6.23	124.8	140.7	6.38
	5.18	20	8.26	28.30	3.31	760	751	0.834	0.988	0.117	6.15	123.0	134.7	6.26
	5.18	20	8.26	28.30	3.61	741	750	0.900	1.012	0.128	6.31	126.2	133.0	6.37
51	4.97	30	8.26	28.30	0.51	790	188	0.066	0.238	0.018	8.88	266.4	1037	11.65
	4.98	30	8.26	28.30	0.53	807	298	0.166	0.369	0.019	8.69	260.7	640.0	10.39
	5.02	30	8.26	28.30	0.41	794	328	0.261	0.413	0.014	8.83	264.9	518.6	10.10
	5.02	30	8.26	28.30	0.51	796	386	0.342	0.485	0.018	8.81	264.3	451.9	9.81
	5.00	30	8.26	28.30	0.43	790	390	0.376	0.494	0.015	8.88	266.4	434.3	9.79
	5.04	30	8.26	28.30	0.41	804	408	0.428	0.507	0.014	8.72	261.6	400.0	9.49
	5.06	30	8.26	28.30	0.39	788	444	0.507	0.563	0.014	8.90	267.0	375.0	9.53
	5.06	30	8.26	28.30	0.20	784	466	0.575	0.594	0.007	8.94	268.2	353.9	9.45
	5.08	30	8.26	28.30	0.32	790	500	0.646	0.633	0.011	8.88	266.4	331.3	9.28
	5.08	30	8.26	28.30	0.24	782	500	0.722	0.639	0.008	8.97	269.1	316.6	9.27
	5.03	30	8.26	28.30	0.43	799	536	0.792	0.671	0.015	8.78	263.4	295.9	8.99
	5.14	30	8.26	28.30	0.00	812	560	0.872	0.690	0.000	8.64	259.2	277.5	8.76
	5.10	30	8.26	28.30	0.32	786	510	0.934	0.649	0.011	8.92	267.6	277.0	8.98

(Continued)

(Sheet 3 of 4)

TABLE I. (Concluded)

Test No.	Carriage Speed V_c fps	Cone Index C	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Clay Numeric N_{c2}*	Clay Numeric N_{c2}*	Clay Numeric N_{c3}	Clay Numeric N_{c4}
52	4.89	38	8.34	28.58	2.35	1556	360	0.034	0.231	0.082	5.82	221.2	1200	8.16
	4.88	38	8.34	28.58	2.38	1585	536	0.128	0.338	0.083	5.71	217.0	607.0	7.01
	4.92	38	8.34	28.58	2.35	1576	640	0.225	0.406	0.082	5.75	218.5	460.4	6.68
	4.90	38	8.34	28.58	2.98	1574	812	0.312	0.516	0.104	5.75	218.5	391.5	6.46
	4.92	38	8.34	28.58	3.01	1566	864	0.356	0.552	0.105	5.78	219.6	367.8	6.41
	4.96	38	8.34	28.58	3.03	1570	914	0.400	0.582	0.106	5.77	219.3	347.0	6.33
	4.96	38	8.34	28.58	3.03	1548	970	0.481	0.627	0.106	5.85	222.3	320.3	6.30
	4.98	38	8.34	28.58	3.03	1550	1040	0.559	0.671	0.106	5.84	221.9	296.7	6.19
	5.02	38	8.34	28.58	3.39	1532	1144	0.635	0.747	0.119	5.91	224.6	281.8	6.18
	5.06	38	8.34	28.58	3.58	1552	1184	0.717	0.763	0.125	5.84	221.9	262.0	6.04
	5.00	38	8.34	28.58	3.69	1542	1164	0.784	0.755	0.129	5.88	223.4	252.4	6.02
	5.00	38	8.34	28.58	3.64	1572	1188	0.858	0.756	0.127	5.76	218.9	236.4	5.85
	5.12	38	8.34	28.58	3.10	1554	1110	0.928	0.714	0.108	5.83	221.5	230.0	5.87
53	5.15	20	8.26	28.30	2.24	726	620	0.367	0.854	0.079	6.44	128.8	212.5	7.12
54	5.19	21	8.26	28.30	3.67	768	736	0.774	0.958	0.130	6.39	134.2	152.5	6.55
55	5.13	36	8.26	28.30	0.14	791	343	0.384	0.434	0.005	10.64	383.0	617.7	11.71
56	5.04	35	8.26	28.30	0.00	806	402	0.790	0.499	0.000	10.15	355.3	400.0	10.39
57	5.15	36	8.34	28.58	3.71	1561	1222	0.775	0.783	0.130	5.50	198.0	225.0	5.64
58	5.13	38	8.34	28.58	2.80	1583	808	0.336	0.567	0.098	5.72	217.4	374.8	6.38

(Sheet 4 of 4)

TABLE II.--FIRST-PASS BRAKED-WHEEL TESTS IN YUMA SAND

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
1	4.85	12.6	8.26	28.30	0.60	772	467	0.367	0.605	0.0212	58.33	22.99
2	4.91	12.9	8.26	28.30	2.84	729	699	0.784	0.959	0.1003	63.24	7.24
3**	--	--	--	--	--	-	--	--	--	--	--	--
4	5.10	6.2	8.26	28.30	1.72	751	459	0.405	0.611	0.0607	29.50	10.73
5	4.95	12.0	8.34	28.58	2.61	1513	861	0.364	0.569	0.0913	29.19	11.58
6**	--	--	--	--	--	--	--	--	--	--	--	--
7	5.07	12.6	8.26	28.30	0.10	764	46	0.126	0.060	0.0035	58.94	38.02
	4.99	12.6	8.26	28.30	0.18	764	263	0.197	0.344	0.0064	58.94	32.78
	5.07	12.6	8.26	28.30	0.44	749	407	0.296	0.543	0.0155	60.12	27.41

(Continued)

* Equations 2 and 6, respectively.

** Tests 3, 6, and 31 were constant-skid tests in each of which sinkage exceeded 4 in. It was determined that when sinkages of this magnitude were attained, the sand buildup interfered with the vertical load applied; therefore, all test data are omitted for which $z \geq 4$ in.

Tests 24-26 were conducted to determine relations not sought in this program.

Test 27 produced results quite different from those obtained in all of the remaining tests; no clear-cut reason for this dissimilarity is known. Data for this test are omitted so that trends established by all of the remaining tests will not be obscured.

(Sheet 1 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
7	5.13	12.6	8.26	28.30	0.60	741	450	0.378	0.607	0.0212	60.77	23.41
	5.13	12.6	8.26	28.30	0.64	753	460	0.390	0.611	0.0226	59.80	22.45
	5.13	12.6	8.26	28.30	0.70	741	467	0.416	0.630	0.0247	60.77	21.57
	5.13	12.6	8.26	28.30	0.82	741	485	0.453	0.654	0.0290	60.77	19.87
	5.15	12.6	8.26	28.30	1.10	737	507	0.520	0.688	0.0388	61.10	17.04
	5.17	12.6	8.26	28.30	1.47	733	557	0.589	0.760	0.0519	61.44	14.29
	5.13	12.6	8.26	28.30	1.72	730	585	0.648	0.801	0.0607	61.69	12.03
	5.17	12.6	8.26	28.30	2.16	726	637	0.712	0.877	0.0763	62.03	9.69
	5.17	12.6	8.26	28.30	2.58	722	669	0.778	0.926	0.0911	62.37	7.36
	5.17	12.6	8.26	28.30	2.70	718	665	0.796	0.926	0.0953	62.72	6.76
	5.19	12.6	8.26	28.30	2.76	714	682	0.818	0.955	0.0975	63.07	6.03
	5.21	12.6	8.26	28.30	2.86	722	680	0.838	0.942	0.1010	62.37	5.28
	5.17	12.6	8.26	28.30	3.16	718	718	0.896	1.000	0.1116	62.72	3.35
	5.21	12.6	8.26	28.30	3.32	718	749	0.938	1.043	0.1172	62.72	1.98
8	4.98	17.9	8.34	28.58	1.42	1530	878	0.358	0.574	0.0497	43.05	17.29
9	4.95	14.4	4.17	14.08	0.21	96	52	0.396	0.542	0.0149	67.48	25.02
10	5.16	13.9	4.17	14.08	0.89	104	80	0.799	0.769	0.0632	60.13	6.38
11	5.30	16.2	4.19	14.12	2.09	169	171	0.790	1.012	0.1482	43.62	4.85
12	5.18	15.8	4.19	14.12	0.89	186	115	0.373	0.618	0.0631	38.66	15.05
13	5.09	7.0	4.17	14.08	0.74	87	52	0.361	0.598	0.0526	36.20	14.45

(Continued)

(Sheet 2 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
14	4.84	6.6	4.17	14.08	0.38	92	23	0.049	0.250	0.0270	32.37	25.73
	4.83	6.6	4.17	14.08	0.36	86	34	0.135	0.395	0.0256	34.53	21.84
	4.86	6.6	4.17	14.08	0.39	84	44	0.227	0.524	0.0277	35.35	18.51
	4.84	6.6	4.17	14.08	0.48	84	45	0.306	0.536	0.0341	35.35	15.80
	4.84	6.6	4.17	14.08	0.53	77	48	0.330	0.623	0.0376	38.56	16.41
	4.83	6.6	4.17	14.08	0.52	81	52	0.361	0.642	0.0369	36.66	14.63
	4.85	6.6	4.17	14.08	0.55	78	49	0.389	0.628	0.0391	38.07	14.33
	4.89	6.6	4.17	14.08	0.73	80	51	0.474	0.638	0.0518	37.12	11.56
	4.87	6.6	4.17	14.08	0.86	74	51	0.550	0.689	0.0611	40.12	10.37
	4.86	6.6	4.17	14.08	1.12	73	61	0.628	0.836	0.0795	40.67	8.44
	4.87	6.6	4.17	14.08	1.26	72	69	0.706	0.958	0.0895	41.24	6.59
	4.85	6.6	4.17	14.08	1.40	73	72	0.762	0.986	0.0994	40.67	5.17
	4.87	6.6	4.17	14.08	1.44	70	70	0.791	1.000	0.1023	42.42	4.69
	4.87	6.6	4.17	14.08	1.50	64	67	0.813	1.047	0.1065	46.39	4.56
	4.87	6.6	4.17	14.08	1.58	70	71	0.861	1.014	0.1122	42.42	3.06
	4.85	6.6	4.17	14.08	1.67	69	74	0.939	1.072	0.1186	43.03	1.33
	4.86	6.6	4.17	14.08	1.82	70	84	0.970	1.200	0.1293	42.42	0.64
15	5.12	16.5	4.17	14.08	0.00	97	7	0.032	0.072	0.0000	76.53	62.84
	5.11	16.5	4.17	14.08	0.00	90	33	0.122	0.367	0.0000	82.48	53.67
	5.13	16.5	4.17	14.08	0.00	87	39	0.213	0.448	0.0000	85.32	45.94
	5.14	16.5	4.17	14.08	0.00	91	46	0.298	0.505	0.0000	81.57	37.04
	5.15	16.5	4.17	14.08	0.04	82	48	0.373	0.585	0.0028	90.53	35.24
	5.15	16.5	4.17	14.08	0.07	89	52	0.390	0.584	0.0050	83.41	31.32

(Continued)

(Sheet 3 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
15	5.15	16.5	4.17	14.08	0.00	84	50	0.416	0.595	0.0000	88.37	31.37
	5.17	16.5	4.17	14.08	0.07	84	52	0.441	0.619	0.0050	88.37	29.69
	5.19	16.5	4.17	14.08	0.18	81	51	0.509	0.630	0.0128	91.64	26.26
	5.18	16.5	4.17	14.08	0.24	82	57	0.568	0.695	0.0170	90.53	22.30
	5.21	16.5	4.17	14.08	0.31	77	50	0.643	0.649	0.0220	96.40	19.10
	5.21	16.5	4.17	14.08	0.50	79	62	0.711	0.785	0.0355	93.96	14.73
	5.20	16.5	4.17	14.08	0.60	79	64	0.765	0.810	0.0426	93.96	11.78
	5.21	16.5	4.17	14.08	0.62	81	68	0.784	0.840	0.0440	91.64	10.50
	5.20	16.5	4.17	14.08	0.66	81	74	0.806	0.914	0.0469	91.64	9.37
	5.19	16.5	4.17	14.08	0.70	82	64	0.843	0.780	0.0497	90.53	7.41
	5.23	16.5	4.17	14.08	0.80	80	68	0.910	0.850	0.0568	92.79	4.27
	5.20	16.5	4.17	14.08	0.84	78	73	0.955	0.936	0.0597	95.17	2.17
16	5.09	14.5	4.19	14.12	0.08	187	70	0.127	0.374	0.0057	35.28	22.71
	5.09	14.5	4.19	14.12	0.16	180	77	0.211	0.428	0.0113	36.66	19.82
	5.10	14.5	4.19	14.12	0.28	177	90	0.286	0.508	0.0199	37.28	17.34
	5.12	14.5	4.19	14.12	0.38	180	101	0.360	0.561	0.0270	36.66	14.66
	5.14	14.5	4.19	14.12	0.44	177	103	0.386	0.582	0.0312	37.28	14.12
	5.12	14.5	4.19	14.12	0.51	178	104	0.415	0.584	0.0362	37.07	13.19
	5.14	14.5	4.19	14.12	0.58	178	111	0.443	0.624	0.0411	37.07	12.40
	5.14	14.5	4.19	14.12	0.70	176	121	0.511	0.688	0.0496	37.49	10.69
	5.12	14.5	4.19	14.12	0.96	174	133	0.579	0.764	0.0681	37.92	9.07

(Continued)

(Sheet 4 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
16	5.14	14.5	4.19	14.12	1.08	173	134	0.646	0.774	0.0766	38.14	7.49
	5.15	14.5	4.19	14.12	1.26	169	149	0.718	0.882	0.0894	39.04	5.96
	5.16	14.5	4.19	14.12	1.42	168	154	0.774	0.917	0.1007	39.28	4.72
	5.17	14.5	4.19	14.12	1.52	168	159	0.794	0.946	0.1078	39.28	4.28
	5.16	14.5	4.19	14.12	1.55	168	156	0.825	0.928	0.1099	39.28	3.60
	5.20	14.5	4.19	14.12	1.68	166	161	0.858	0.970	0.1191	39.75	2.93
	5.19	14.5	4.19	14.12	1.88	166	171	0.921	1.030	0.1333	39.75	1.60
	5.19	14.5	4.19	14.12	1.95	168	178	0.968	1.060	0.1383	39.28	0.63
17	5.18	7.6	4.17	14.08	1.35	85	82	0.770	0.965	0.0959	40.22	4.93
18	5.18	21.5	4.19	14.12	0.47	197	112	0.407	0.568	0.0333	48.78	17.66
19	5.04	21.3	4.19	14.12	1.47	168	147	0.783	0.875	0.1043	57.28	6.59
20	4.92	20.0	4.17	14.08	0.78	90	70	0.791	0.778	0.0554	99.98	11.06
21	4.94	20.8	4.17	14.08	0.12	90	52	0.378	0.578	0.0085	103.97	40.05
22	5.06	20.6	4.17	14.08	0.00	94	32	0.088	0.340	0.0000	98.59	69.34
	5.08	20.6	4.17	14.08	0.00	89	40	0.190	0.449	0.0000	104.13	58.74
	5.08	20.6	4.17	14.08	0.00	90	48	0.278	0.533	0.0000	102.97	48.68
	5.10	20.6	4.17	14.08	0.07	89	49	0.366	0.550	0.0050	104.13	41.13
	5.08	20.6	4.17	14.08	0.06	88	48	0.389	0.545	0.0043	105.32	39.63
	5.08	20.6	4.17	14.08	0.08	81	48	0.418	0.592	0.0057	114.42	40.44
	5.10	20.6	4.17	14.08	0.22	85	58	0.500	0.682	0.0156	109.03	31.93
	5.08	20.6	4.17	14.08	0.35	78	53	0.577	0.679	0.0249	118.82	28.56

(Continued)

(Sheet 5 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
22	5.08	20.6	4.17	14.08	0.50	75	56	0.652	0.747	0.0355	123.57	23.79
	5.10	20.6	4.17	14.08	0.62	78	64	0.726	0.820	0.0440	118.82	17.58
	5.12	20.6	4.17	14.08	0.70	80	66	0.764	0.825	0.0497	115.85	14.59
	5.12	20.6	4.17	14.08	0.73	84	67	0.792	0.798	0.0518	110.33	12.14
	5.12	20.6	4.17	14.08	0.72	92	71	0.819	0.772	0.0511	100.74	9.57
	5.12	20.6	4.17	14.08	0.74	88	65	0.885	0.739	0.0526	105.32	6.24
	5.12	20.6	4.17	14.08	0.80	83	70	0.934	0.843	0.0568	111.66	3.75
23	5.28	20.9	4.19	14.12	0.01	194	15	0.014	0.077	0.0007	48.67	42.91
	5.25	20.9	4.19	14.12	0.05	192	63	0.124	0.328	0.0035	49.18	31.86
	5.26	20.9	4.19	14.12	0.10	179	77	0.224	0.430	0.0071	52.75	27.78
	5.27	20.9	4.19	14.12	0.16	179	97	0.308	0.542	0.0113	52.75	23.47
	5.30	20.9	4.19	14.12	0.37	182	94	0.362	0.516	0.0262	51.88	20.67
	5.27	20.9	4.19	14.12	0.36	182	104	0.401	0.571	0.0255	51.88	19.03
	5.28	20.9	4.19	14.12	0.39	180	105	0.410	0.583	0.0277	52.46	18.86
	5.23	20.9	4.19	14.12	0.50	177	112	0.452	0.633	0.0355	53.35	17.48
	5.25	20.9	4.19	14.12	0.73	175	116	0.524	0.663	0.0518	53.96	14.90
	5.24	20.9	4.19	14.12	0.90	173	133	0.595	0.769	0.0638	54.58	12.48
	5.24	20.9	4.19	14.12	1.18	167	128	0.672	0.766	0.0837	56.54	10.19
	5.23	20.9	4.19	14.12	1.50	160	132	0.744	0.825	0.1064	59.02	8.11
	5.26	20.9	4.19	14.12	1.62	176	149	0.762	0.847	0.1149	53.65	6.82
	5.26	20.9	4.19	14.12	1.68	170	162	0.791	0.953	0.1191	55.55	6.14
	5.24	20.9	4.19	14.12	1.68	189	188	0.820	0.994	0.1191	49.96	4.72
	5.24	20.9	4.19	14.12	1.81	171	155	0.886	0.906	0.1284	55.22	3.24
	5.24	20.9	4.19	14.12	1.81	175	169	0.928	0.966	0.1284	53.96	.98

(Continued)

(Sheet 6 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
24-27**	--	--	--	--	--	--	--	--	--	--	--	--
28	4.80	11.5	8.26	28.30	0.19	793	42	0.069	0.053	0.0067	51.83	38.22
	4.76	11.5	8.26	28.30	0.19	781	220	0.168	0.282	0.0067	52.63	31.06
	4.83	11.5	8.26	28.30	0.57	767	407	0.285	0.531	0.0201	53.59	24.98
	4.84	11.5	8.26	28.30	0.79	762	450	0.381	0.590	0.0279	53.94	20.65
	4.84	11.5	8.26	28.30	0.82	760	460	0.392	0.605	0.0290	54.08	20.22
	4.84	11.5	8.26	28.30	0.94	760	473	0.430	0.622	0.0332	54.08	18.62
	4.88	11.5	8.26	28.30	1.09	758	501	0.483	0.661	0.0385	54.22	16.54
	4.89	11.5	8.26	28.30	1.53	752	556	0.572	0.739	0.0540	54.65	13.32
	4.86	11.5	8.26	28.30	2.06	744	594	0.652	0.798	0.0727	55.24	10.64
	4.89	11.5	8.26	28.30	2.69	732	659	0.734	0.900	0.0950	56.15	8.04
	4.84	11.5	8.26	28.30	2.93	729	673	0.773	0.923	0.1035	56.38	6.81
	4.88	11.5	8.26	28.30	3.14	730	685	0.800	0.938	0.1109	56.30	5.94
	4.88	11.5	8.26	28.30	3.22	729	694	0.808	0.952	0.1137	56.38	5.70
	4.89	11.5	8.26	28.30	3.25	731	699	0.813	0.956	0.1148	56.23	5.53
	4.87	11.5	8.26	28.30	3.61	729	727	0.892	0.997	0.1275	56.38	3.13
	4.92	11.5	8.26	28.30	4.08	725	786	0.969	1.084	0.1441	56.69	0.89

(Continued)

(Sheet 7 of 9)

TABLE II. (Continued)

Test No.	Carriage Speed V_c fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Numeric N_{s2}*
29	5.05	18.0	8.34	28.58	0.18	1552	84	0.116	0.054	0.0063	42.68	28.14
	4.97	18.0	8.34	28.58	0.35	1533	417	0.190	0.272	0.0122	43.21	24.38
	5.12	18.0	8.34	28.58	0.80	1516	769	0.320	0.507	0.0280	43.69	19.98
	5.20	18.0	8.34	28.58	1.06	1521	819	0.364	0.538	0.0371	43.55	17.28
	5.16	18.0	8.34	28.58	1.22	1521	834	0.388	0.548	0.0427	43.55	16.42
	5.16	18.0	8.34	28.58	1.32	1520	863	0.406	0.568	0.0462	43.58	15.81
	5.20	18.0	8.34	28.58	1.71	1509	962	0.492	0.638	0.0598	43.90	13.11
	5.17	18.0	8.34	28.58	2.24	1495	1050	0.570	0.702	0.0783	44.31	10.86
	5.16	18.0	8.34	28.58	2.98	1485	1171	0.646	0.788	0.1042	44.60	8.75
	5.19	18.0	8.34	28.58	3.75	1740	1302	0.719	0.886	0.1311	45.06	6.85
30	4.94	19.0	8.26	28.30	0.00	792	12	0.102	0.015	0.0000	85.74	58.36
	4.88	19.0	8.26	28.30	0.01	780	285	0.191	0.365	0.0004	87.06	49.01
	5.00	19.0	8.26	28.30	0.19	789	444	0.314	0.563	0.0067	86.06	37.84
	5.02	19.0	8.26	28.30	0.20	772	450	0.380	0.583	0.0071	87.96	33.74
	5.00	19.0	8.26	28.30	0.24	776	450	0.405	0.580	0.0085	87.51	31.82
	5.00	19.0	8.26	28.30	0.30	768	459	0.432	0.598	0.0106	88.42	30.30
	4.96	19.0	8.26	28.30	0.46	763	473	0.484	0.620	0.0162	89.00	27.08
	5.00	19.0	8.26	28.30	0.74	755	501	0.571	0.664	0.0261	89.94	21.98
	5.00	19.0	8.26	28.30	1.13	762	549	0.646	0.720	0.0399	89.11	17.49
	5.00	19.0	8.26	28.30	1.40	744	547	0.722	0.735	0.0494	91.27	13.72
	4.96	19.0	8.26	28.30	0.00	792	102	0.013	0.129	0.0000	85.74	75.96

(Continued)

(Sheet 8 of 9)

TABLE II. (Concluded)

Test No.	Carriage Speed V_s fps	Cone Index Gradient G_b	Tire Width b in.	Tire Diam d in.	Tire Sinkage z in.	Tire Load W lb	Wheel Drag D lb	Slip S	Drag Ratio D/W	Sinkage Ratio z/d	Basic Sand Numeric N_{s1}*	Sand Numeric N_{s2}*
30	5.05	19.0	8.26	28.30	1.89	774	661	0.794	0.854	0.0667	87.73	9.56
	5.04	19.0	8.26	28.30	1.88	770	640	0.802	0.831	0.0664	88.19	9.21
	5.00	19.0	8.26	28.30	1.92	754	625	0.828	0.829	0.0678	90.06	8.11
	5.00	19.0	8.26	28.30	2.02	762	666	0.870	0.874	0.0713	89.11	5.99
	5.02	19.0	8.26	28.30	2.08	760	663	0.944	0.872	0.0734	89.35	2.54
31**	--	--	--	--	--	--	--	--	--	--	--	--
32	5.10	18.8	8.26	28.30	1.73	772	632	0.794	0.819	0.0611	87.03	9.48
33	5.12	19.6	8.26	28.30	0.48	775	466	0.413	0.601	0.0169	89.92	32.13

(Sheet 9 of 9)

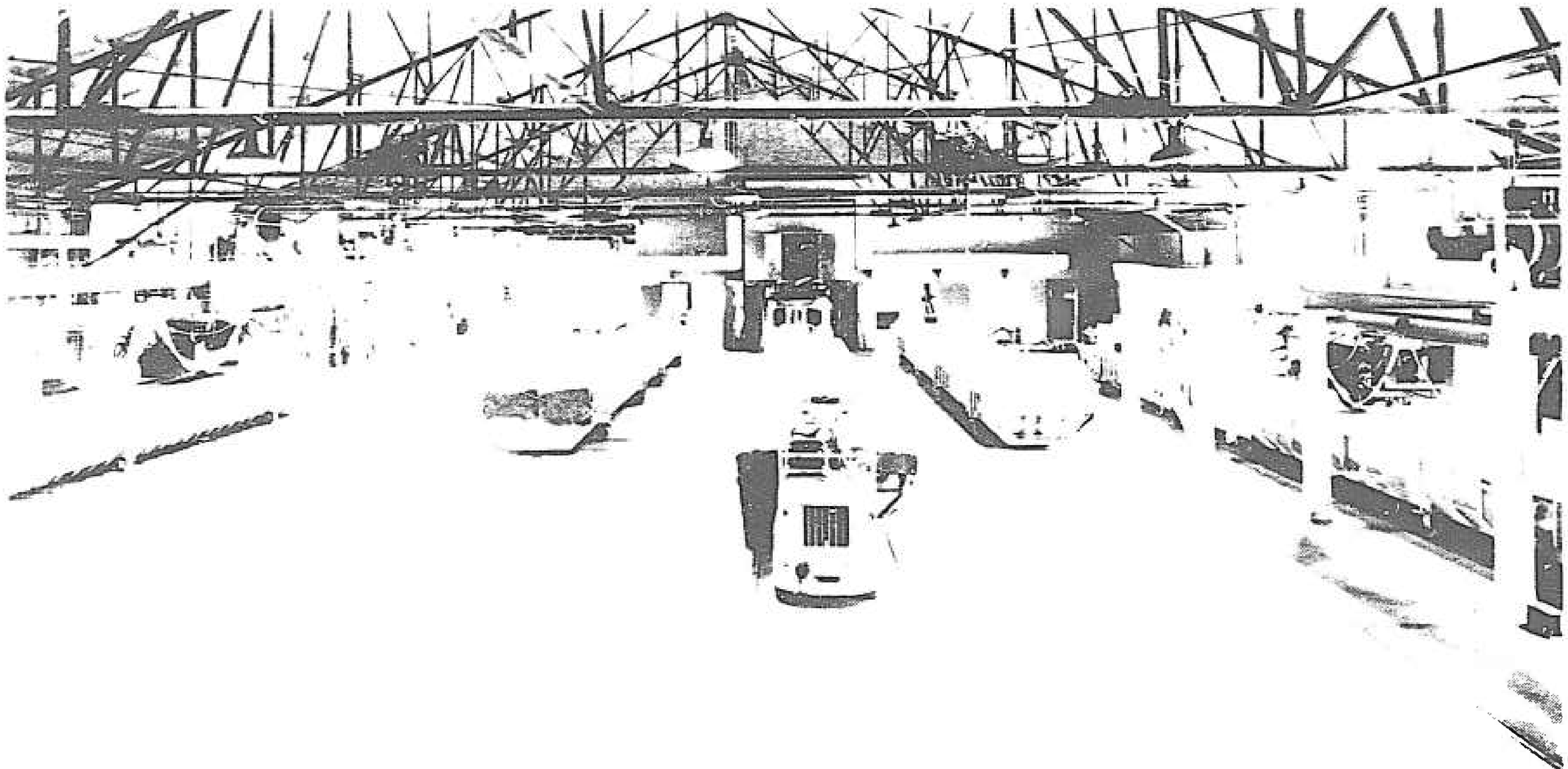
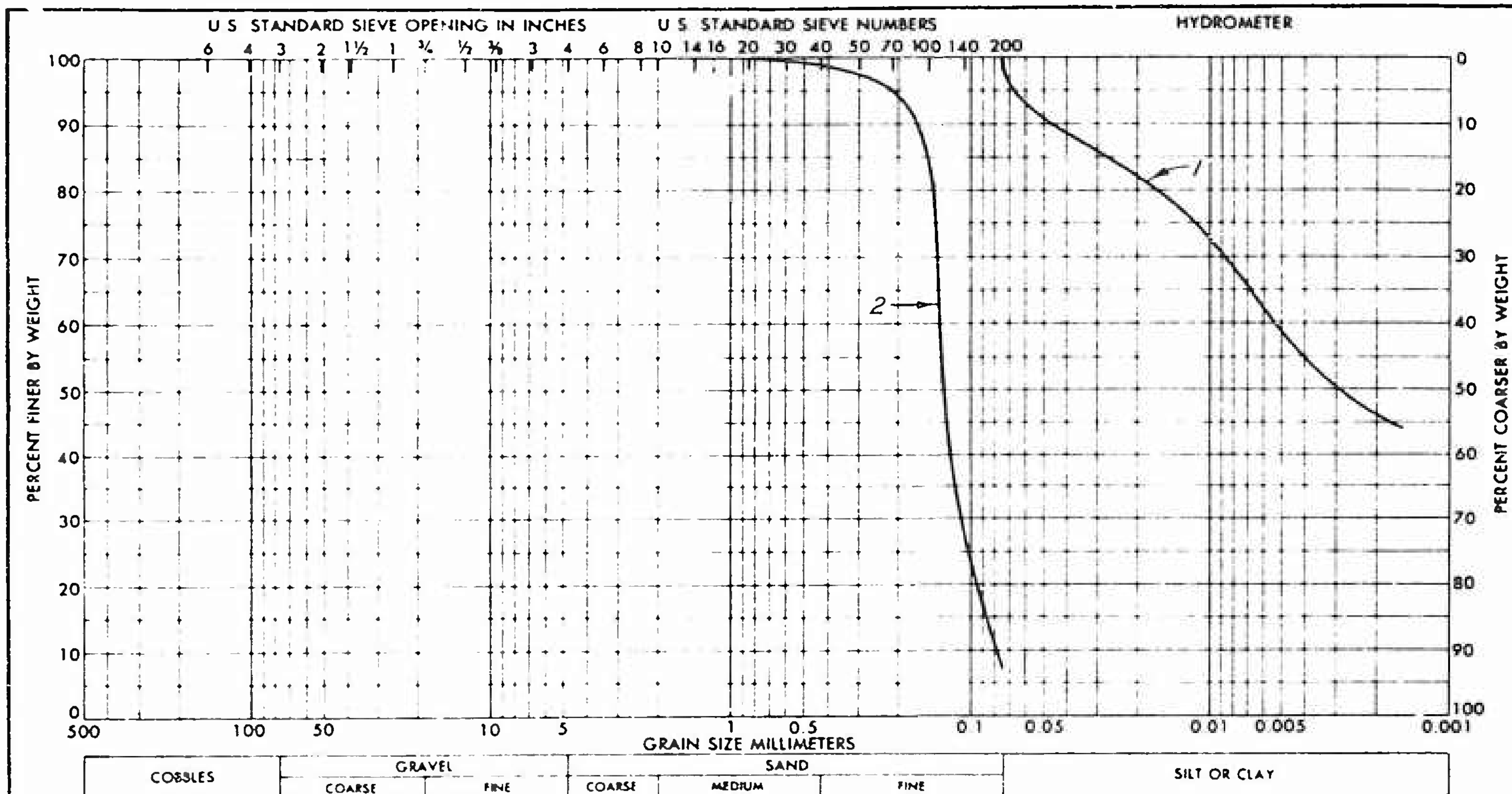


Figure 1. WES Mobility Small-Scale-Testing Facility



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1		HEAVY CLAY CH	VARIOUS	70	25	45
2		FINE SAND SP-SM	AIR-DRY	-	-	-

Figure 2. Mechanical Analysis of Test Soils

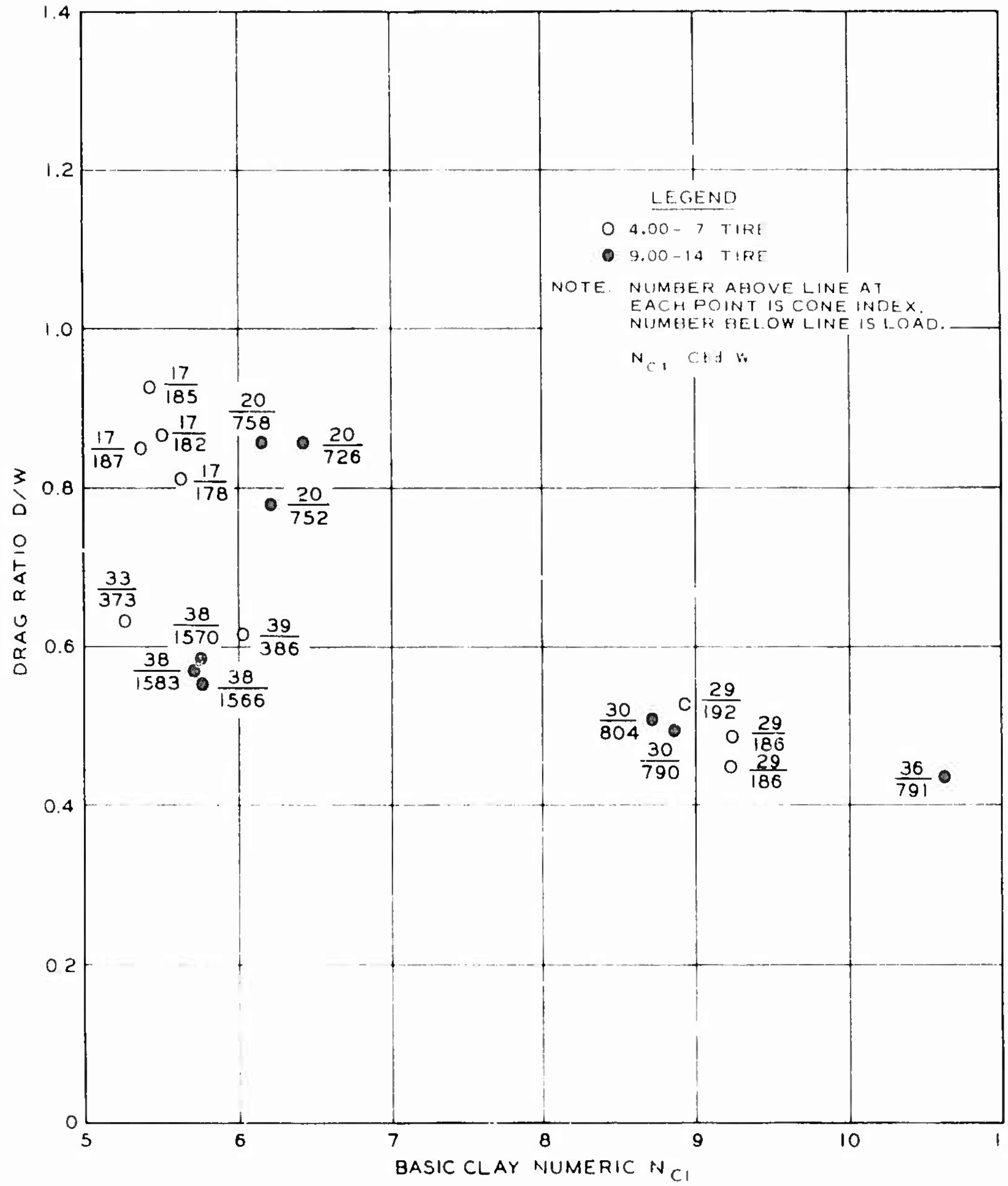


Figure 3. Relation of Drag Ratio to Basic Clay Numeric, N_{cl}, for Two Tires at 40 $\pm$ 5 Percent Slip

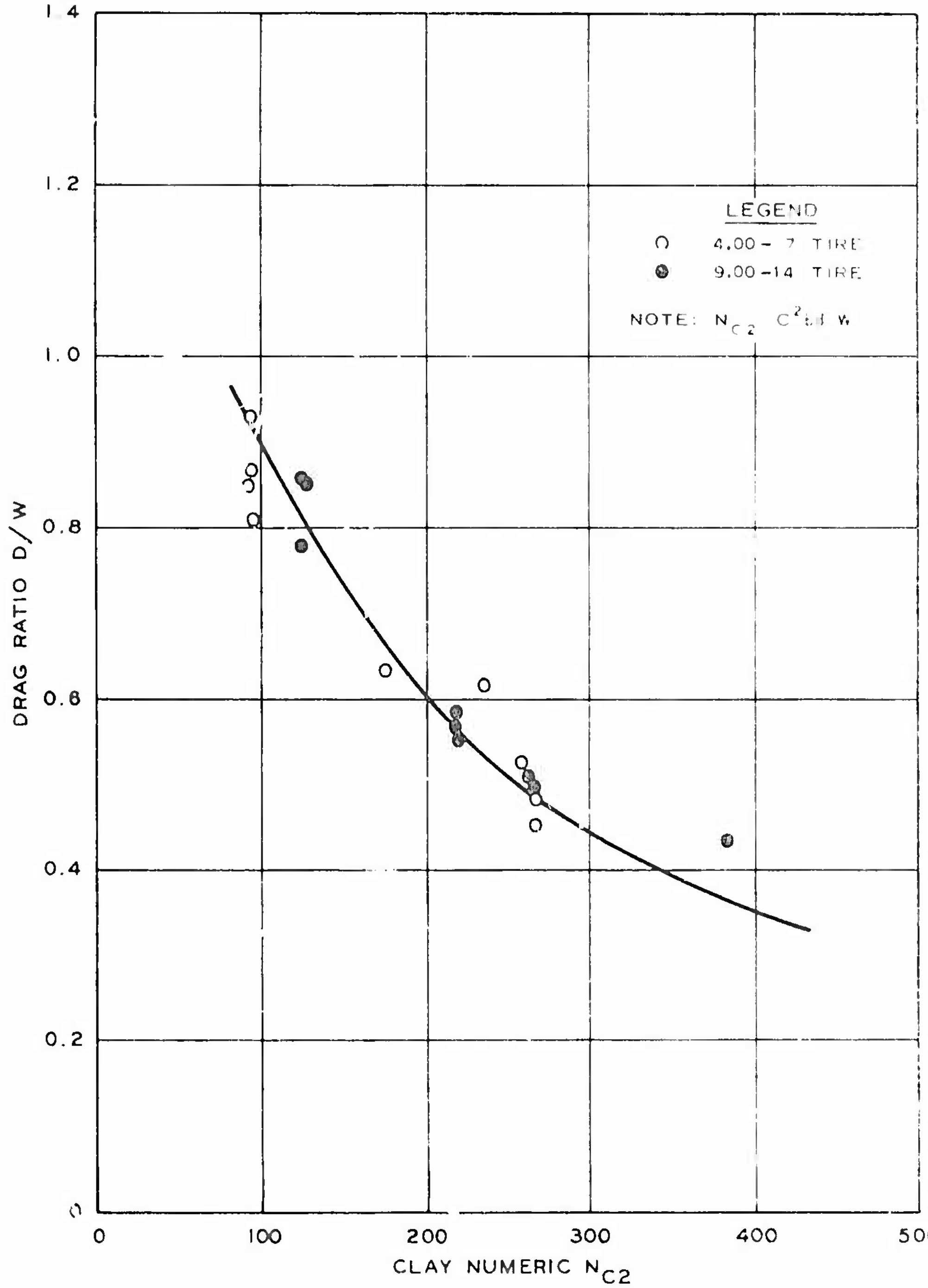


Figure 4. Relation of Drag Ratio to Clay Numeric, N_{C2}, for Two Tires at 40 ± 5 Percent Slip

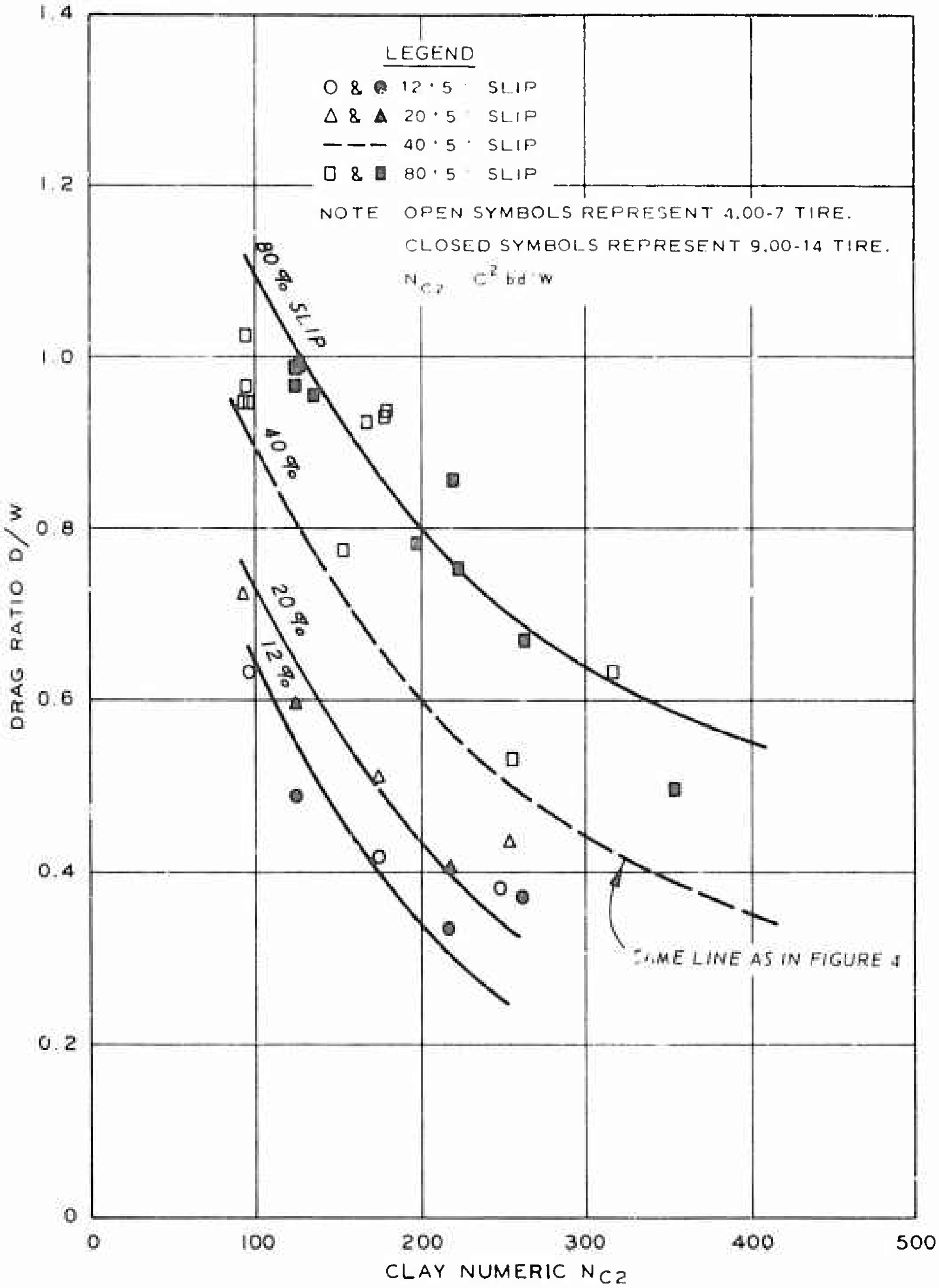


Figure 5. Relation of Drag Ratio to Clay Numeric, N_{c2}, at Four Braked-Wheel Slip Levels

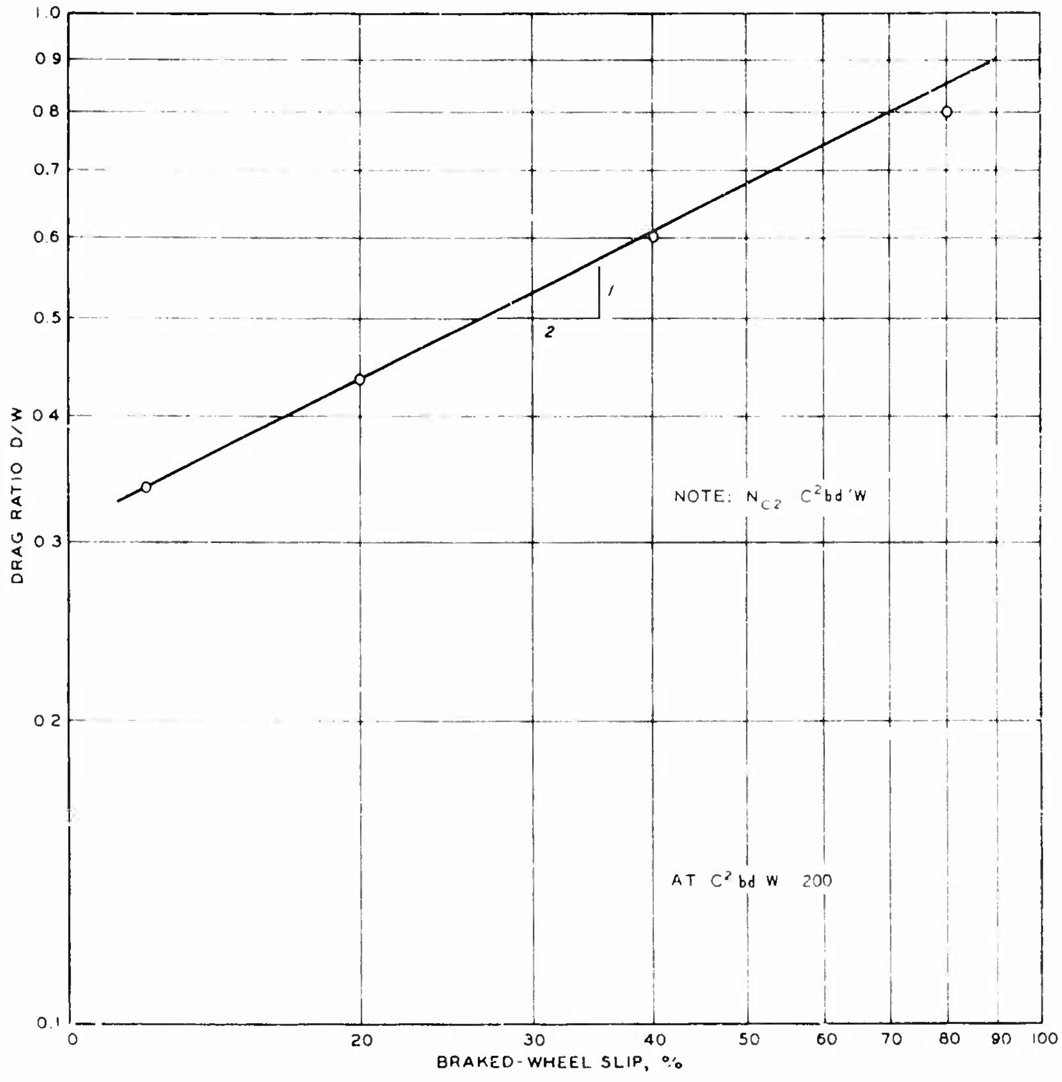


Figure 6. Logarithmic Relation of Drag Ratio to Percent Slip at N_{c2} = 200 for Braked-Wheel Tests

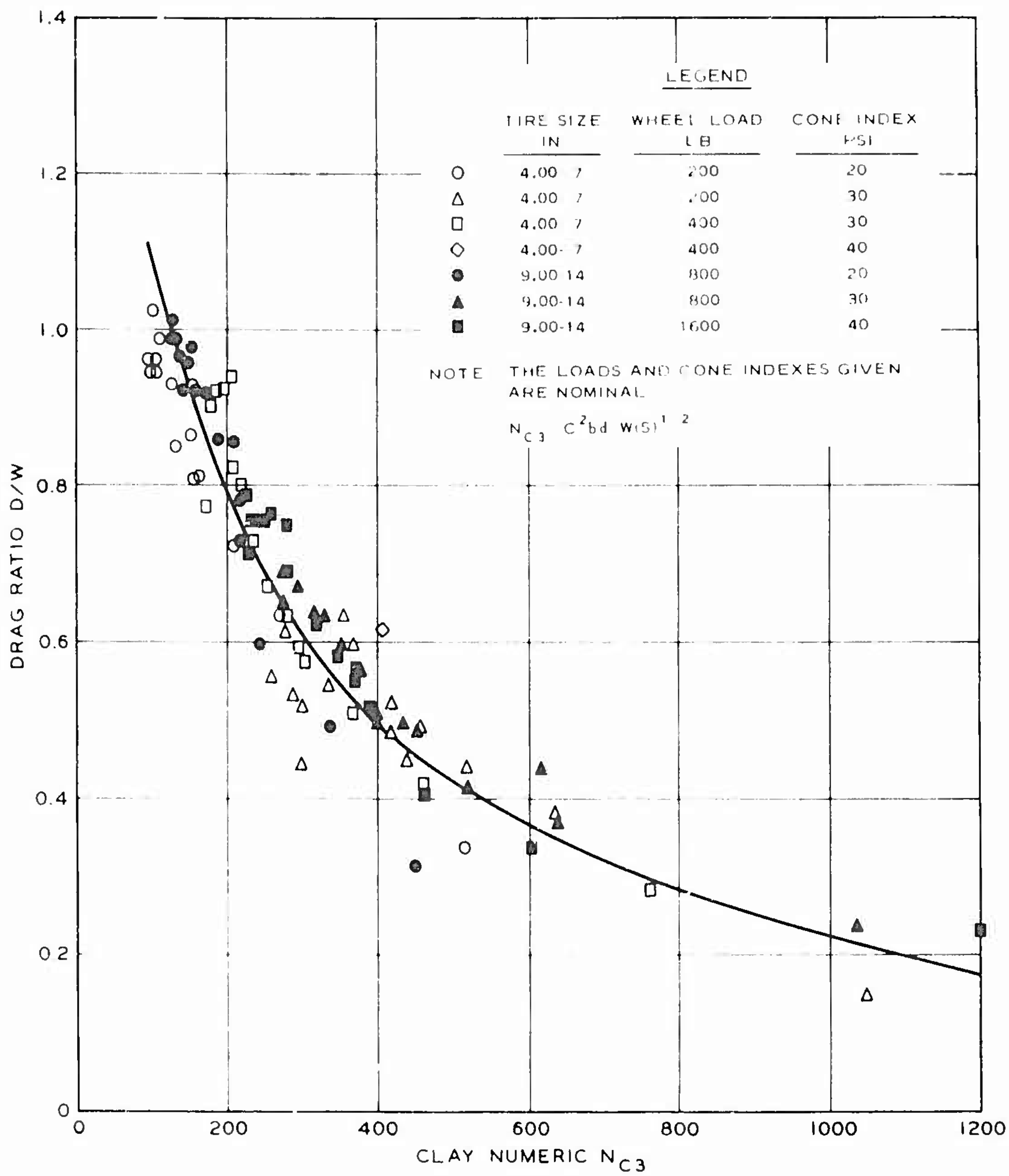


Figure 7. Relation of Drag Ratio to Clay Numeric, N_{c3}, for Braked-Wheel Tests of Two Tires

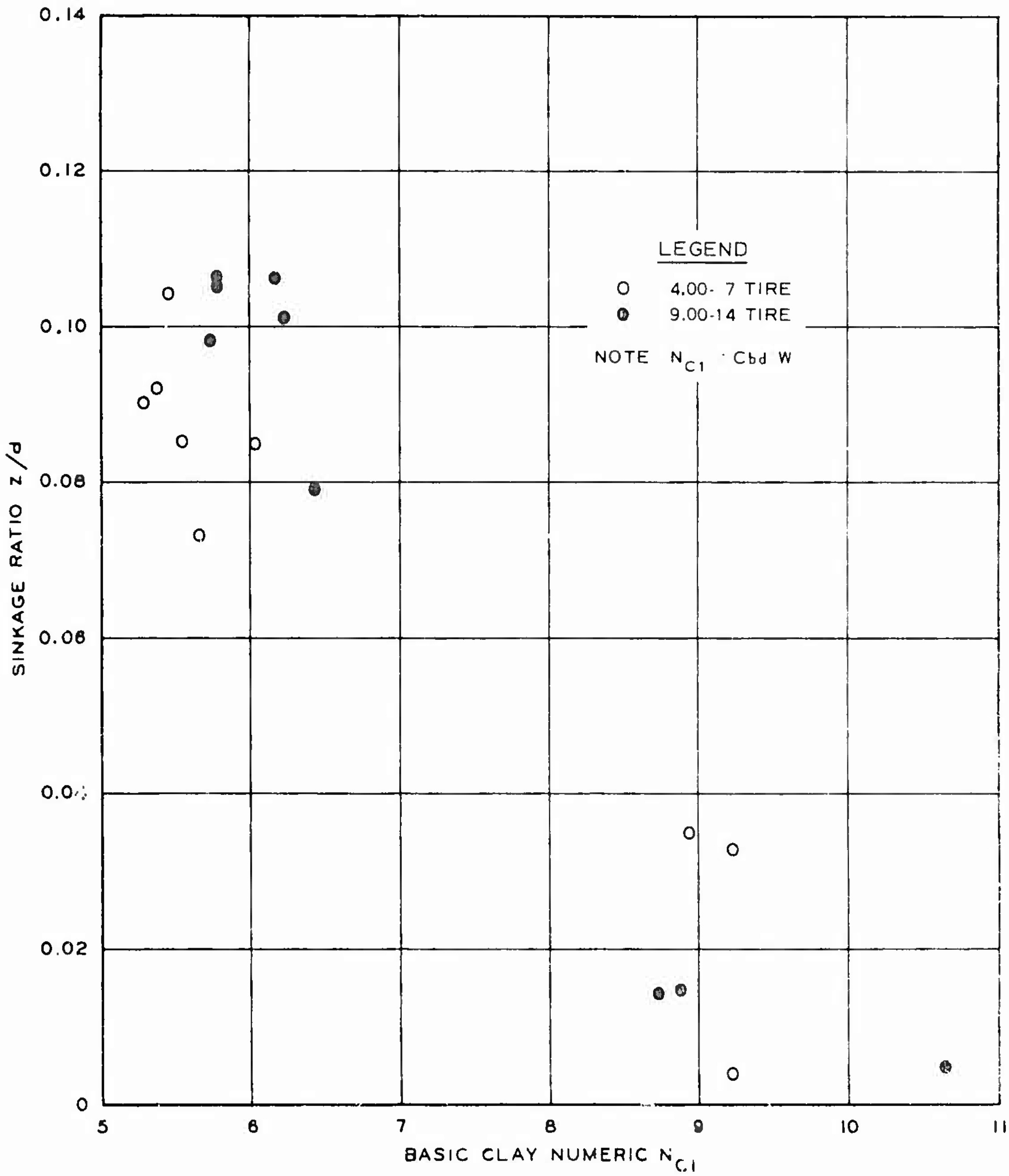


Figure 8. Relation of Sinkage Ratio to Basic Clay Numeric, N_{c1}, for Two Tires at 40 ± 5 Percent Braked-Wheel Slip

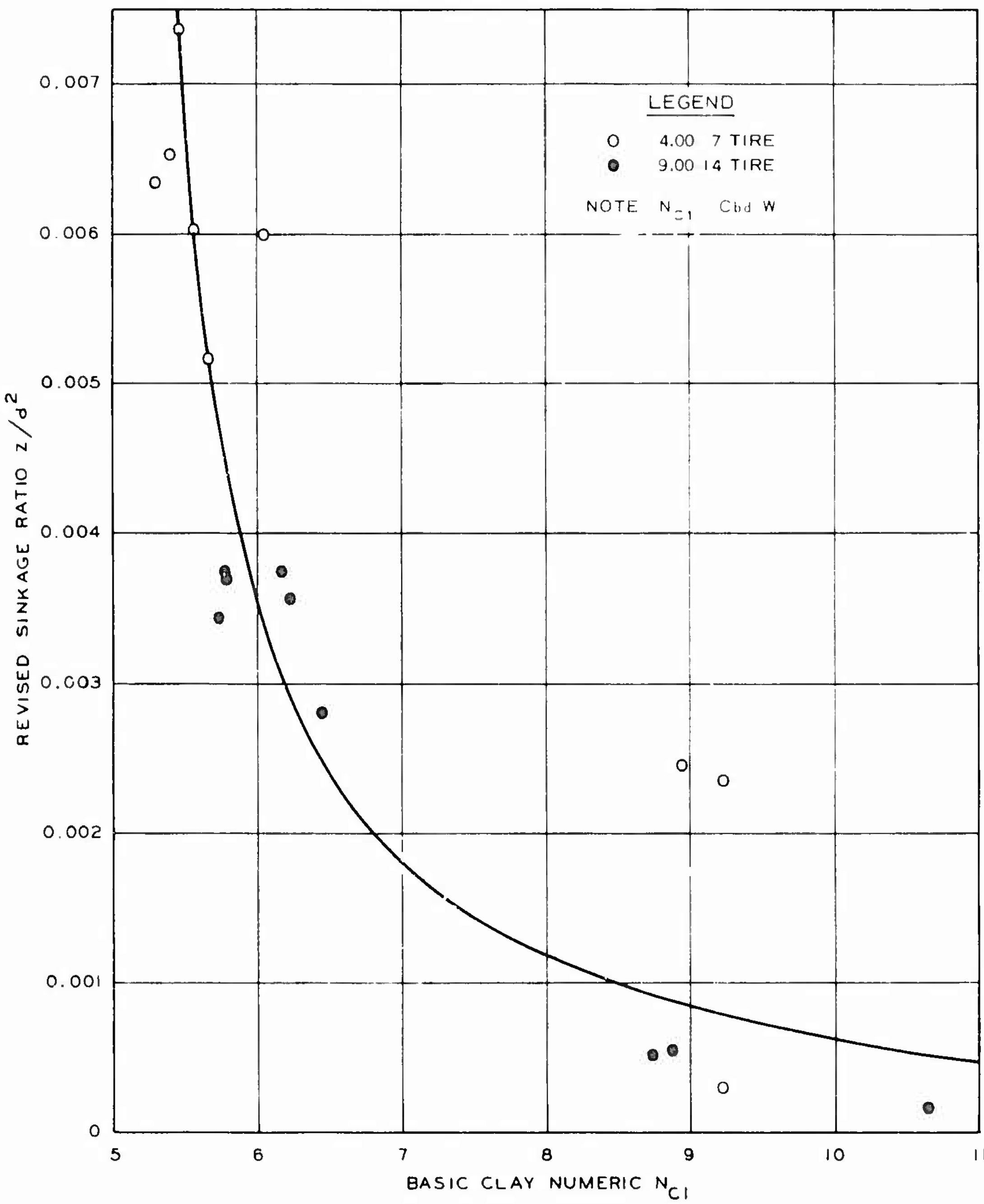


Figure 9. Relation of Revised Sinkage Ratio to Basic Clay Numeric, N_{cl}, for Two Tires at 40 $\pm$ 5 Percent Braked-Wheel Slip

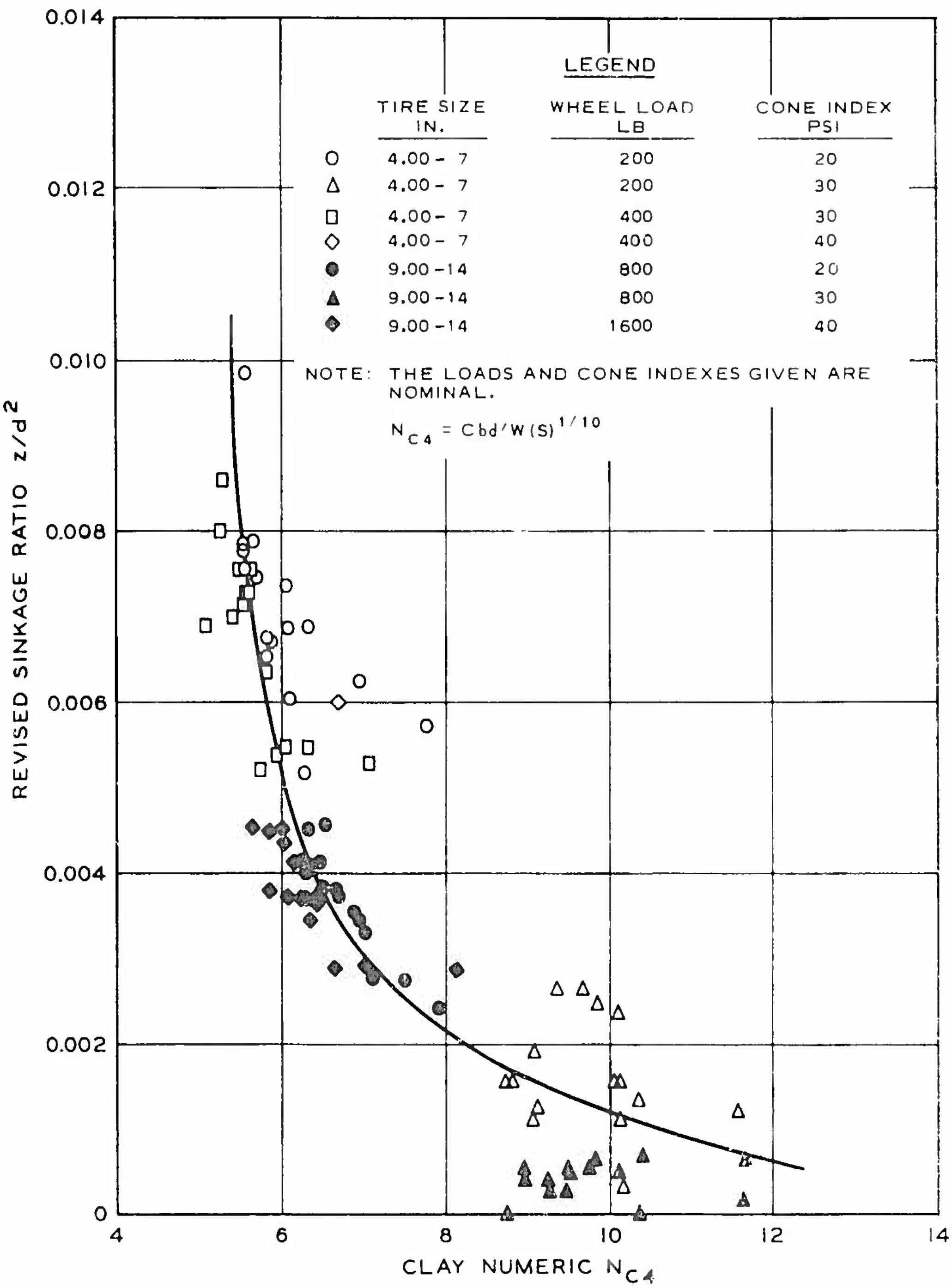


Figure 10. Relation of Revised Sinkage Ratio to Clay Numeric, N_{c4}, for Braked-Wheel Tests of Two Tires

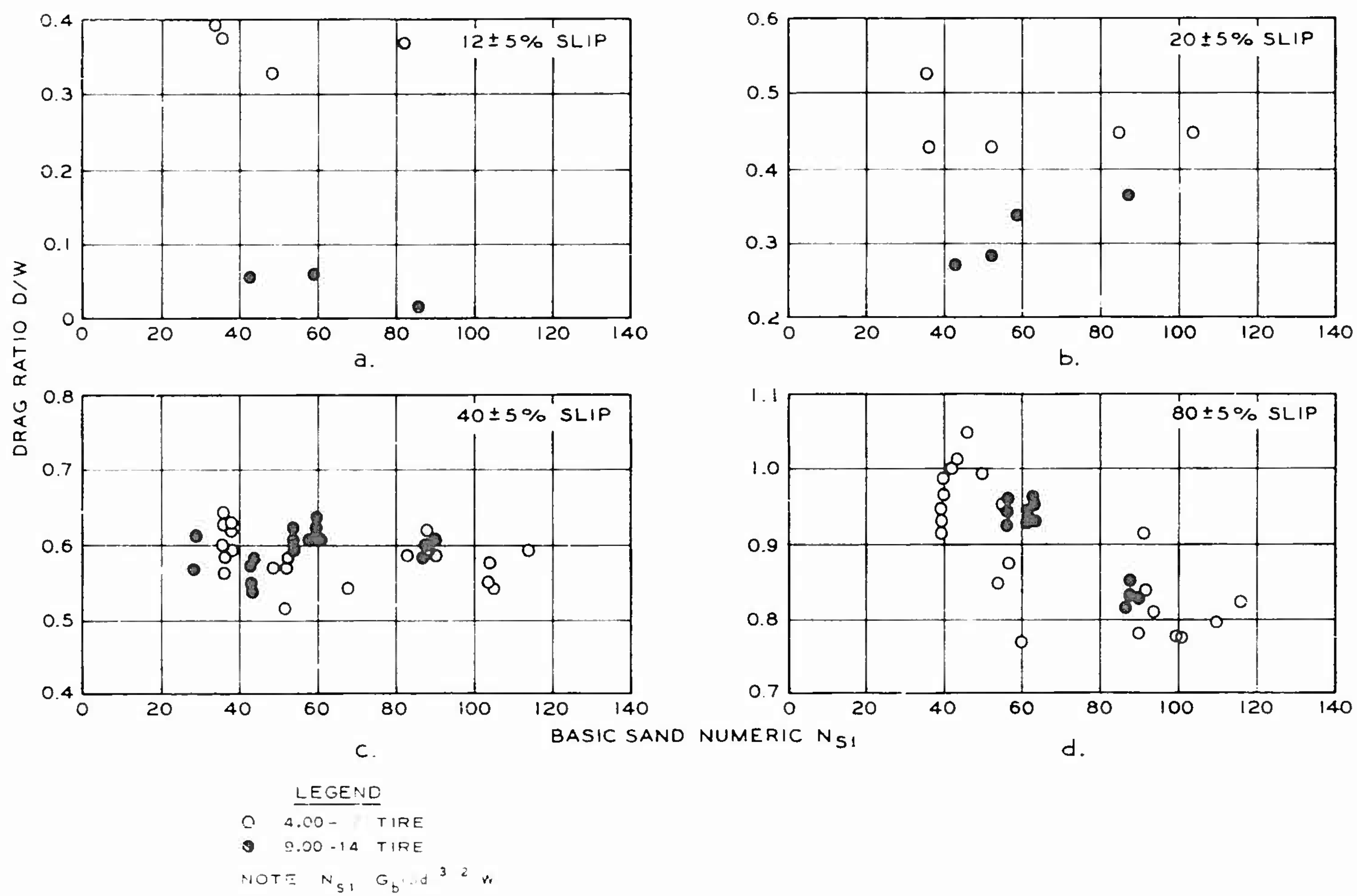


Figure 11. Relation of Drag Ratio to Basic Sand Numeric, N_{s1}, for Two Tires at Four Braked-Wheel Slip Levels

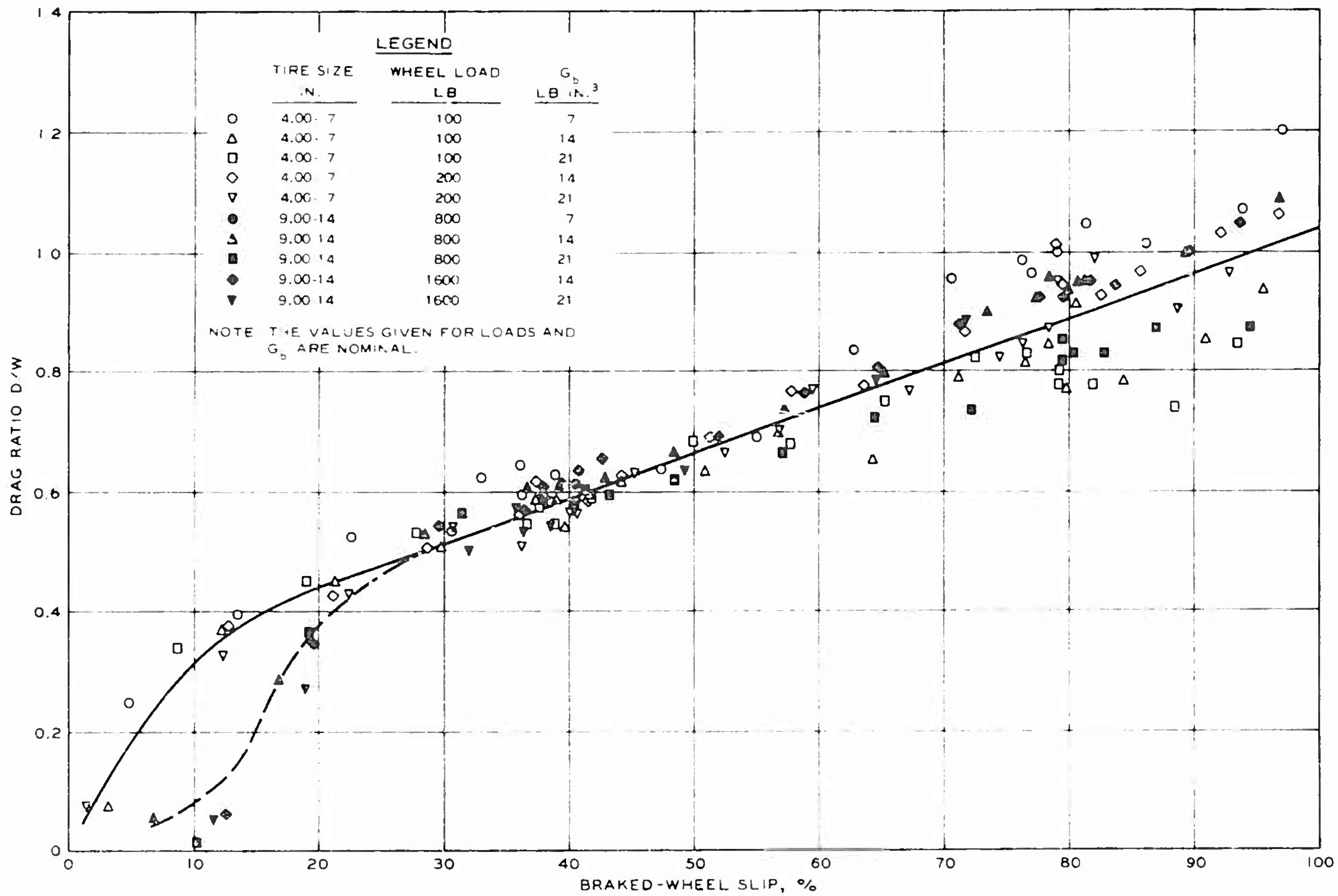


Figure 12. Relation of Drag Ratio to Percent Slip for Braked-Wheel Tests of Two Tires in Sand

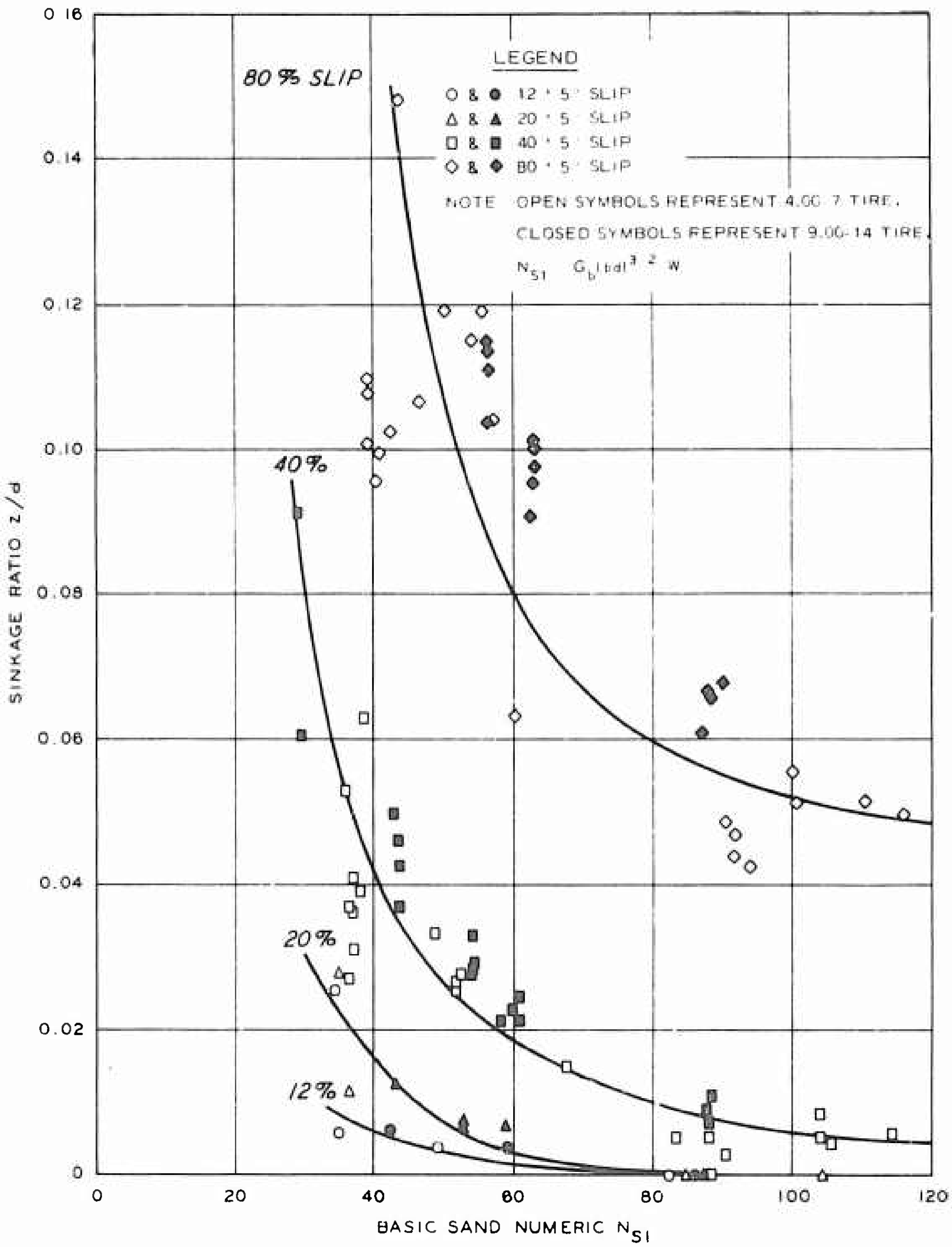


Figure 13. Relation of Sinkage Ratio to Basic Sand Numeric, N_{s1}, for Two Tires at Four Braked-Wheel Slip Levels

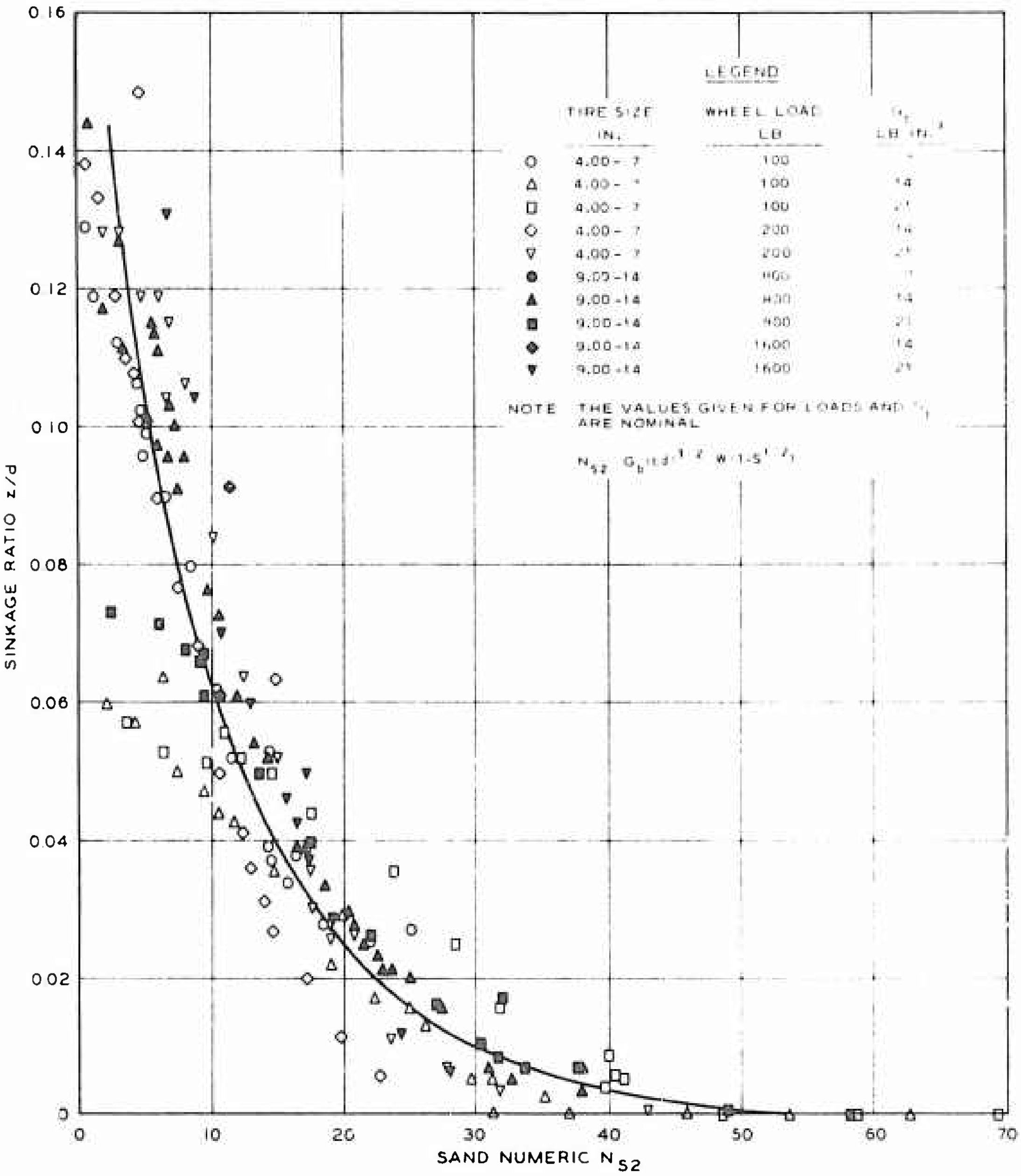


Figure 14. Relation of Sinkage Ratio to Sand Numeric, N_{S2}, for Braked-Wheel Tests of Two Tires

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   b. Report No. 2, Analysis of Tests in Yuma Sand Through August 1962, by C. J. Powell and A. J. Green, Jr., August 1965.

   c. Report No. 3, Tests in Clay Through November 1962, by R. D. Wismer, February 1966.

   d. Report No. 4, Analysis of Tests in Sand From September 1962 Through November 1963, by G. W. Turnage and A. J. Green, Jr., February 1966.

2. ____________, A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils, by D. R. Freitag, Technical Report No. 3-688, Vicksburg, Miss., August 1965.